Integrated Proving Ground

5G Wireless Testbed

November 2019

Proposed IPG Master Plan for 5G Wireless Network Including;

4G/5G wireless Core

4G/5G wireless Radio Access Network

Software Defined Network

Cloud Platform

IoT Platform

Cybersecurity Platform

Test Equipment Platform

Introduction: Texas A&M University received $50 million dollars from the State of Texas Legislature to “establish and equip a proving ground site and to commercialize and manufacture critical emerging technologies for infrastructure networks, public safety, and national defense”.

Of the monies allocated up to $8 million is being requested to support a wireless network to be built following the international 3GPP wireless standards and service providers’ best practices. This network would support all of the anticipated sub-elements of the 5G infrastructure. These include the Next Generation Core (manages communications), the 5G Radio Access Network, or RAN (the cell sites), the Software Defined Network, or SDN (supporting network data slicing), the Edge Cloud (moving analytics closer to the end user), the IoT aggregation infrastructure (aggregation, normalization and security of the 32 billion IoT devices expected to drive the systems by the year 2025), test and measurement systems (needed to collect and store data required by researchers), and the cybersecurity layer (designed to protect the testbed and to allow cybersecurity research to be conducted). **As designed, this network would not only support the testing requirements of the proving ground but it would also be able to utilize the infrastructure to greatly enhance the research opportunities. This is must if we are going to be able to sustain ongoing operational costs without requiring a very significant contribution from the TAMU System.**

While most of the other elements of the of the Testbed are primarily dedicated to defense testing, the proposed wireless network is being designed to be flexible enough to also support public safety, transportation, energy, telemedicine, smart and connected communities, service provider networks and other areas requiring such a testbed. This approach not only assures sustainability but also provides opportunities for other industry partners and federal agencies to apply additional funding that could be used to expand the capabilities of the testbed.

One of the other stipulations in the funding was that it would “create jobs and promote Texas”, as listed in Chapter 605 (S.B. 1), Acts of the 85^{th} Legislature, Regular Session, 2017.

To support this, the platform could be used for training and jobs creation. Programs that could be supported are described below.

1. TEEX has an existing Wireless Warriors program in which they recruit signal corps soldiers that have recently been discharged. This is short term training that provides training for the entry level wireless installer.

2. Blinn College and Austin Community College have expressed a desire to create a two-year associates level wireless network engineer certificate that would have the skill set to do fault diagnostics and troubleshooting.
3. The testbed could be made available to under graduate and graduate faculty members for use in their course work in many areas (engineering, transportation, public policy, physics, etc.).
4. The Department of Defense has already identified many areas where the testbed could be used to train communication officers and signal corps soldiers.
5. The NSA is investigating ways to utilize the testbed for cybersecurity training.
6. FEMA recently expanded the public safety Incident Command Structure (ICS) to add an Information Technology Systems Unit Lead (ITSL) position. This person is responsible for supporting communications infrastructure in the field for multi-jurisdictional disaster response.

Recommended Governance and Operations;

Governance and operations are two critical portions of the proposed 5G network. Governance deals with setting the strategic direction and oversite of the testbed. Operations deals with the performance of the day to day tasks that are required to make the testbed a success. We recommend the establishment of a governance board with a user advisory committee that would set the direction of the 5G testbed. We further recommend that the TAMU Internet2 Technology Evaluation Center (ITEC) under the direction of the governance board be responsible for the daily operation of the infrastructure. The detailed work for configuration of the 5G network, SDN, edge cloud, IoT aggregation and cybersecurity would be contracted out to the best field vendor selected. The ITEC would coordinate all efforts and serve as a project manager. More detailed information for both of these follow;

Governance - A governance committee should be established which would be responsible for setting the strategic direction of the testbed. Representation from the TAMUS stakeholders that makeup the board would; 1.) Set strategy, approve budget, promote use of the testbed by presenting at conferences in their respective segments and write grants that would utilize the testbed. Representation should come from any Center that would be likely to do testing, research or training on 5G wireless systems. Examples would be;

- TEES – as agency managing funds they should chair the committee
- TCAT – DoD
- BCDC – DoD
- TEEX – Public Safety
- ITEC – Public Safety

- TTI – Transportation
- TAMU College of Engineering – 5G Wireless
- Agriculture – Rural Agriculture
- Center for Cyber Security
- LoneStar UAS Center
- Center for Infrastructure Renewal
- University of Texas Wireless Network Communications Group (WNCG)

Examples of advisory board members would be;

- US. Department of Defense
- US Department of Homeland Security
- US Department of Transportation
- National Security Agency
- Texas Department of Public Safety
- Canadian Defense Research/ Development Canada (DR-DC) or Canadian DoD and Homeland Security.
- Chevrolet
- Ford
- Toyota

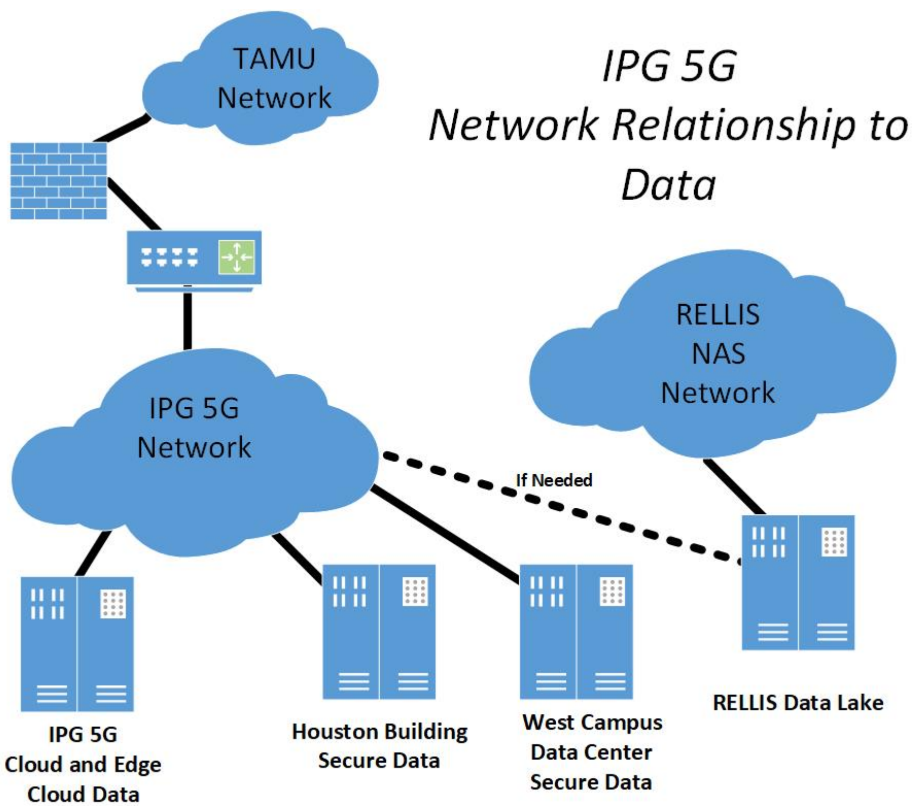
Operations – We recommend that the ITEC be responsible for the daily operations of the 5G testbed. This would be done under the direction of the governance board. The ITEC has been running research networks since 2004. In 2012 the Texas A&M University System received a $9.6 million grant from the United States Department of Commerce to construct a statewide network. The network connected 8 TAMUS campuses over 150 miles of fiber optic cable partnering with 5 telephone companies and one city. This project was completed within the 2 years allowed and under budget. The ITEC has also been managing carrier grade 4G networks supporting research funded by the United States Department of Homeland Security since 2011. The ITEC currently has 6 proposals pending and 2 more funded that would leverage the 5G network. In other words we would be one of our own largest initial customers. While there is initial support funding in the request, we feel confident that we would have enough of our own funding to continue three staff that could provide ongoing support after the two years. ITEC responsibilities would include;

- Write requisitions for equipment under TEES guidelines.
- Coordinate fiber and power construction.
- Inventory support (receiving).
- Project Management – Oversee and document all installations and configurations.
- Support TEES communications with in input for webpage, social media and other outreach material.
- Coordinate Campus IT interaction.
- Support researchers with conference/presentation material
- Grant writing support for researchers
- Support network documentation
- Provide annual security audits
- Publish monthly progress report.
- Interface with Proteus for research and production frequency coordination.
- Facilitate monthly governance board meetings and quarterly advisory board meetings.
- Support researcher's requirements for experiments. This includes testbed configuration, data collection and any other requirements.
- Monitor grant solicitations for opportunities and make researchers IPG 5G Wireless of these opportunities.
- Coordinate integration with national and international SDN and 5G initiatives.

Data Storage:

One area that is out of scope of this document and the IPG 5G Wireless Network is that of data storage. While there is a Cloud component (edge, middle and private) to the wireless network, it is our belief that issues like authentication, credentialing, access and retention need to be determined at the governance level and need to be consistent across all data storage platforms. With the nature of clientele that the IPG 5G wireless network is likely to attract there could even be classified information supported so the flexibility to be able to support these requirements needs to be considered at the outset.

In the following diagram the edge cloud component of data storage is included in the IPG 5G portion of this proposal. The Houston Data Center, West Campus Data Center and RELLIS Data Lake are managed by others. To be able to support such connectivity we recommend a separate fiber connection from the IPX 5G wireless network to each of these data centers. Access Control Lists (ACLs) should then be placed in the core Juniper Router assuring no leakage between the external networks. The architecture diagram for data connectivity follows;



Testbed Functional Requirements;

On September 16th and 17th, TEES invited potential testbed users to share their requirements. The 16th involved future partners from the Federal Agencies. The 17th was our industry day. These discussions included all aspects of the testbed but only the areas that could be impacted by the 5G wireless network are discussed in this document. In addition requirements shared by TAMU engineering faculty are provided below.

Requirements shared by TAMU faculty include;

(1) A production level network that can support all the cameras, sensors, data streaming and other applications required by the components of IPG. The data will be processed at a data center located at the upcoming RIC (Research Integration Center) building The performance should be commensurate with a commercial network. This follows along the lines you have indicated.

There are a limited number of cameras that are scheduled in Phase 1 to be installed in the sensor collection infrastructure. These are HD Samsung and Axis cameras. In addition, a number of LIDR, IR and other cameras will be added in phases 2 and 3. Video can be archived using the existing Genotech survellience system. There are two Dell R740 servers scheduled for phases 1 and 3 that can support IoT sensor archiving. They are scheduled to be installed at the ITEC during Phase 1 with the intention of moving them to RIC when it comes on line.

(2) A research network that is fully programmable, which can be reconfigured, hacked, jammed and broken as needed. It should support any new wireless protocol that needs to be designed and tested. It needs to have UEs that are mobile programmable nodes. This is much like the IPG 5G Wireless Atom concept that we based on software defined radios. The Army is very keen on this functionality, as well as industry users, both in the defense area, and outside.

Both the commercial and the open source systems are fully configurable. The open source system will utilize the configuration tools developed by the University of Utah in their POWDER testlab. The commercial systems will be configured using the Enterprise Management System (EMS) provided by the 5G vendor. All configurations will be archived allowing us to revert back to them as needed after each experiment. The testbed will include both SDR open source mobile UEs as well as commercial mobile, softphone and fixed UEs.

(3) *Finally, an indoor testbed, which can support the same kind of research and development environment. This can consist of small cabinets with ethernet ports and power supply within a building, placed roughly at the same spacing as WiFi access points. Programmable nodes or other wireless equipment under test can be placed here. This can be at the RIC building.*
A combination 4G/5G rackmount chassis is scheduled for installation at the ITEC in Phase 1 of the project. This unit is capable supporting indoor research through the extension from the node to the antennae located throughout the building via fiber, coaxial cable or SIPRE connection. This system could be relocated to the RIC as it comes on line. The mmWave radios would be augmented with the use of inbuilding RF reflectors.

INSTRUMENTATION: ***All of the instrumentation requirements are met through the combination of the IoT and the Cloud computing sections of this document.***

Video:

- *Off Platform:*
  - *Programmable/all-weather high-speed Pan/Tilt/Zoom cameras (day and thermal) with overlapping coverage of the entire IPG.*
    - *Centrally controlled with the ability to manually override from a dashboard location.*
    - *Capable of transferring real-time video from camera to data cell via RF.*
    - *Elevate to a 75 degree upward angle.*
    - *Frame rate and resolution to clearly document events at speeds of 45 MPH.*
  - *Handheld video/still photo digital camera capability.*

- *On Platform:*
  - *Self powered-Micro cameras capable of being mounted both inside and outside of the vehicle to capture:*
    - *POV perspective of vehicle*
    - *Internal vehicle operations and coordination including activity and critical display readouts.*
    - *Capable of transmitting real-time video to the HQs via RF.*

Audio:

- *Off Platform:*

- o *All weather audio system both centrally and locally controlled.*
  - *Replicate environmental sounds throughout the space.*
  - *Supports simultaneous events (up to three).*
  - *Capable of being used to communicate (1xway) from HQs to the field as needed.*
- o *Handheld recording devices for the test Team to utilize to record user input/feedback.*

➢ *Sensors:* *The IPG will provide a variety of sensors, trackers, and devices to ensure the capability to track vehicle and system operations as*

well as instigate, track, and analyze specific events (e.g. electronic jamming, cyber penetration). These are planned as

Multi-level systems that can increase/decrease in security and/or classification as needed.

- *Self powered micro sensors mounted on platforms to collect data on performance in support of diagnostics and analytics.*
  - o *Automotive.*
  - o *Communications.*
  - o *Electromagnetic.*
  - o *Cyber.*
  - o *Capability Functionality.*
  - o *Time space position tracking for high accuracy GPS Time/position, and differential GPS will be included with altitude dependent surveillance broadcast receivers.*

COMMUNICATIONS –These requirements are met in the 4G/5G Core, RAN and SDN functionality.

➢ *Licensed wireless 5G spectrum – sub 6 and millimeter wave*

➢ *Private commercial high power 4G and 5G Network*

➢ *Software defined radios providing programmable and guaranteed application requirements*

- *Software defined network with self organizing capabilities, network slices for attack, defend strategies.*
- *Directional and programmable antennas*
- *Fiber connected hyper scale data center*
- *Antenna suitable for high bandwidth and long range will be positioned for wireless telemetry from test vehicles to operators in various local and control and monitoring areas.*
- *Separate "training frequencies and Network" available for instigating electromagnetic and cyber probes and attacks both on platforms and on the network itself as required without impacting simultaneous operations on the IPG and the RELLIS Campus.*
- *The IPG will have an internal administrative communications network consisting of hand held and base station radio systems allowing for constant and uninterrupted Test Communications.*
- *The IPG will have the capability to integrate US Military non-secure C41SR systems into the HQs operations as required.*
- *Must have a secure capability. Much of the data we collect must be protected as it will be classified so the Network should be encrypted. Intent – whatever architecture is being used can be used across military/civilian and classified/non-classified.*
- *The Network must be able to handle multiple simultaneous projects and events (e.g., three tests, with jamming/spoofing, and still collecting data).*
- *Need an info-centric wireless network.*
- *Need point-to-point communication service: Guarantee performance of packet delivery, Actionable and timely information to vehicles, supporting real time voice, video, and control. Private commercial high power 4G and 5G Network*
- *Need information aggregation, dissemination, and retrieval service: Exploit commonality/correlation of vehicle information requirements, focusing on extracting desired information, Real-time situational IPG 5G Wirelessness. Software defined network with self organizing capabilities, network slices for attack, defend strategies.*

- *Need resilient links to support: Coding adapted to signal-to-noise ratio, Connectivity for control channels at low signal-to-noise ratio, Higher data rate for collaboration at higher signal-to-noise ratios*
- *Need a spectrum manager who controls access and management of the spectrum (identify and assign all spectrums, outline restrictions, and monitor for*
- *Need to be able to isolate nodes on the network.*
- *Allow communications characterization and mapping (radio wave forms).*
- *signing*
- *Look at use of passive reflectors (to affect gain).*
- *To test APNT properly we need Land and SAT based GPS environments.*
- *Need to have ground crew, test directory, safety officer, GCS / flight test personnel on the network: Needs to support multiple channels: Flight crew; Flight crew and test coordinator; Flight crew, TC, GCS crew; TC and discipline engineers.*

CYBERSECURITY This functionality was a major consideration when designing the Core, RAN, SDN, Cloud and Sensors

- *Cyber Range capable of representing or being integrated with multiple heterogeneous operating systems.*
- *Cyber Range capable of allowing the integration of multiple hardware components (up to 100K endpoints; radios, nav devices, sensors, etc.).*
- *Cyber Range capable of being coupled with M&S environments to add/extend context.*
- *Integration with simulation to provide significant efficiencies that enable more frequent and more accurate events (NCR).*
- *Enable rapid emulation of complex, operCyber Range capable of connecting to other Cyber Ranges.*
- *rationally representative network environments (NCR).*

- *Supports a diverse user base by accommodating a wide variety of event types (R&D, information assurance, compliance, malware analysis, etc.) and communities (testing, training, research, etc.) (NCR).*
- *Requirements to conduct testing that cannot or should not occur on open operational networks.*
- *Requirements to test advanced cyberspace tactics, techniques, and procedures that require isolated environments of complex networked systems (e.g., movement on the Internet). Must have a secure network capability to protect the devices being tested and to allow for cyber testing of vulnerabilities and resiliency of both sensors and platforms.*
- *The need to rapidly and realistically represent operational environments at different levels of security, fidelity, and/or scale (e.g., Blue [friendly] force, Red [adversary] force, and Gray [neutral] networks).*
- *The need for precise control of the test environment that allows for rapid reconstitution to a baseline checkpoint, reconfiguration, and repeat of complex test cases; this would include the need for rapid variation of conditions to evaluate hundreds of scenarios.*
- *Support multiple concurrent tests.*
- *Allow sanitization to restore all exposed systems to a known, clean state – Allows assets to be reused even when they are exposed to the most malicious and sophisticated uncharacterized code (NCR).*
- *The IPG needs a stand-alone testing cyber network and a support network. One allows for the vulnerability testing while the other allows for data and test execution.*
- *Allow bringing collected data up a layer, virtualize it, and introduce malware.*

DATA CAPTURE AND STOREAGE This functionality is contained within the Cloud (Private CORD and edge) environment.

- *Capture:*
    - *Manual. Downloadable sensors to capture all data elements on platform and external (communications, video, databus, automotive, performance).*

- *RF capability for Real-time streaming for select internal and external data elements.*
- *Every data record file shall have a time stamp (1 millisecond accuracy) associated with the data and will have a start and stop time.*
- *Data Kiosk as a service station platform download without human interface. Position at the three physical locations (Mobility Challenge Course, Subterranean Test Area, and Off-Road Test Area).*

➢ *<u>Storage:</u>*

- *Sensors (internal and external) will be capable of storing up to 24 hours or 1 TB of data onboard.*
- *A hard stand facility consisting of servers capable of storing XX of data indefinitely.*
- *Overarching architecture to support data warehousing with front-end tools to support collection, assurance, curation, and storage in a manner to facilitate follow-on data analytics.*
- *<u>Display:</u>*
- *Numerous interoperable and integrated work stations within the test HQs element for interactive data tracking, coordination, and curation, diagnostics, and analytics.*
- *Must have a playback capability.*
- *Display Wall. Tailorable display providing the customer with situational IPG 5G Wirelessness and limited situational understanding.*
    - *Video (external and internal)*
    - *Simulation feeds for larger context*
    - *Tailored Platform performance data*
    - *Tracking of initiated and ongoing conditions (cyber, electromagnetic)*
    - *Descriptive Analytics and diagnostics*

<u>Transportation Application that can leverage the 5G Wireless Network</u>: "Infrastructure Enabled Autonomy" (IEA): This is a concept that provides a novel way of distributing autonomous intelligence between vehicles and an extensive network of Road-Side-Units (RSUs) by leveraging connectivity enabled by 5G. The primary benefits of this approach are potential for improved transportation safety and new usage and business models (autonomy-as-a-service). The RSUs are essentially poles on the side of the road that carry sensors, edge computing and wireless communication end-units.

Requirements to support the above application demonstration and evaluation: As part of the IPG 5G WIRELESS proposal, we would like to develop and evaluate the concept on a 2 mile stretch of roadways. Towards this this would an ideal setup:

- 8 5G sites (approximately 400m apart, covering a total distance of 2 miles)
- 32 poles installed with power capability (about 100m apart covering the 2 miles above)
  - For each pole: 1 5G end-user unit
  - We will work with device makers to add a suite of sensors + edge computing to each pole. (E.g. Schreder or WiFiber or another company

Project Phases

Phase 0 October 2019 **–** Validate requirements and architecture – On September 17th and 18th of 2019 we invited in Federal Agency and Industry potential end users of the testbed to solicit input as to the requirements. The results of these meetings are provided later in this plan.

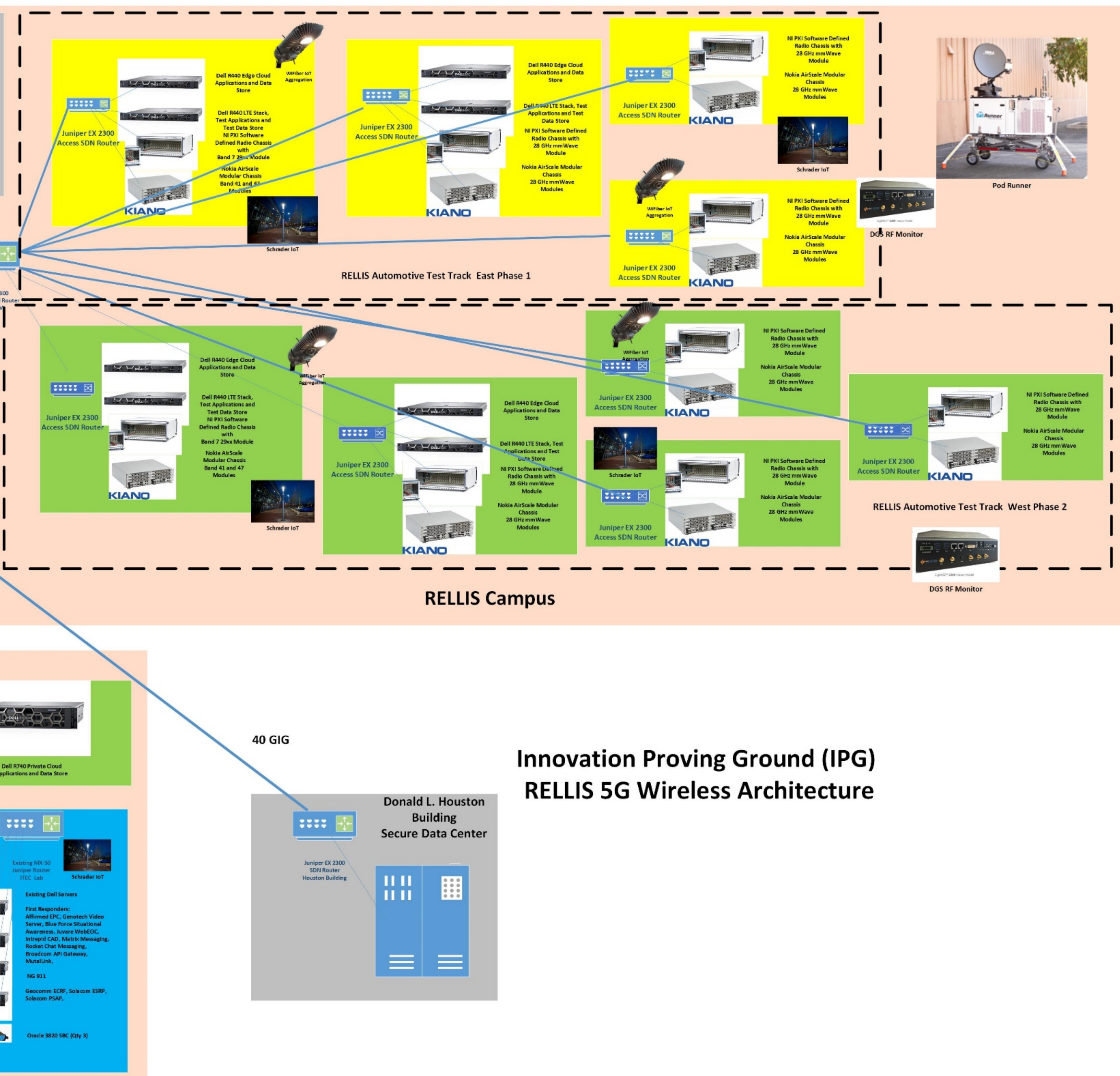
Phase 1 November 2019 – March 2020 **–** Install core systems for 4G EPC and prototype RAN at the ITEC labs. This would include the foundation of the Cloud services, the IoT services, the test equipment and a selection of the UE devices. During Phase 2 the fiber and power installation will begin for the RELLIS and one Disaster City® phase 3 site. Install the core SDN router, firewall and ITEC router.

Phase 2 April 2020 – August 2020 – Install 3 mmWave RAN nodes and one sub six gigahertz RAN node at RELLIS on the easternmost runway. Install RELLIS SDN, RELLIS cloud, two of the IoT aggregation platforms and the test systems at RELLIS. Accept delivery on the mobile IPG 5G WIRELESS node that is to function as a Cellular on Wheels (COW) for the research platform.

Phase 3 September 2020 – March 2021 – Install 4 mmWave RAN nodes and one sub six gigahertz RAN node at RELLIS on the westernmost runway. This is to include RAN, Cloud, IoT, and test system platforms. Install second Disaster City® node. This work would be coordinated with the Phase II TAMUS Facilities infrastructure project.

Phase 4 March 2021 – August 2021 – Upgrade the 4G EPC to a 4G/5G NSA NG-PC. This would be accomplished as soon as the wireless core vendor has the 3GPP compliant release available.

A diagram depicting the IPG 5G Wireless Architecture follows.



Innovation Proving Ground (IPG)
RELLIS 5G Wireless Architecture

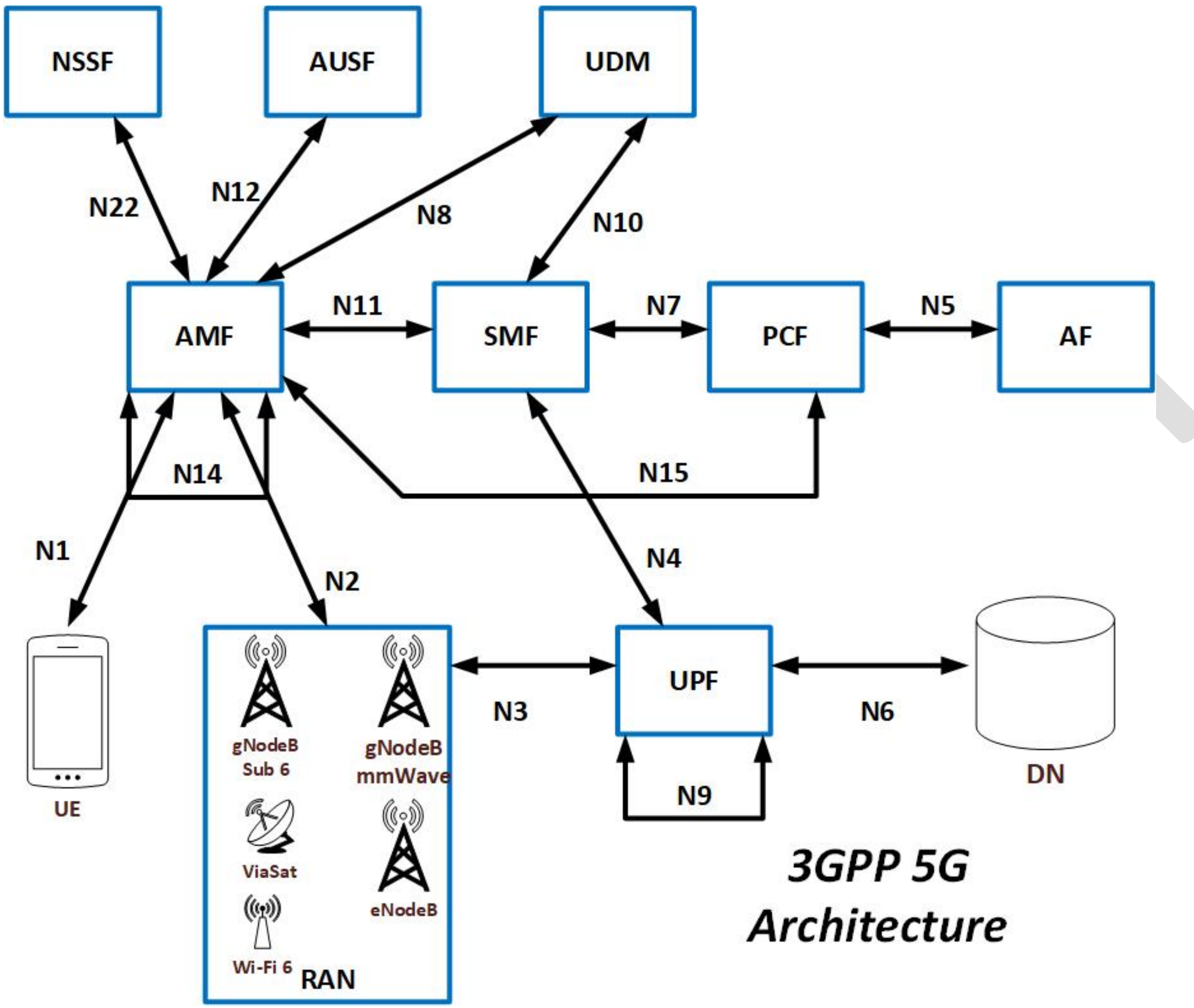
A more detailed explanation of the IPG 5G WIRELESS platform subsystems follows.

IPG 5G WIRELESS CORE - The 3GPP international standards body has formally defined the wireless network to include the Enhanced Packet Core or EPC for 4G wireless and the Radio Access Network (RAN). The core is responsible for authentication (HSS), prioritization of traffic (PCRF), access to the internet (PGW) and securing the connection between the end users device (UE) and the core which is the job of the packet gateway (PGW).

The 5G core referred to as the Next Generation Packet Core or NG-PC is significantly more complex which was required in order to be able to distribute the architecture, support network slicing and support other functions. Over all the same functionality exists between 4G and 5G it is just managed in a more mature manner in 5G.

At this point in time the 5G RAN is pretty well defined and the gNodeBs (5G cell sites) are being deployed by Verizon, AT&T and others in early trials. 3GPP however has not yet completed their work on the 5G core so the strategy that we are adopting for the deployment of IPG 5G WIRELESS platform. There is currently a 4G Core from Affirmed networks in the ITEC lab. This project would add a commercial Next Generation Packet Core (NG-PC) as well as an Open Source Enhanced Packet Core (EPC) to the network. This allow core to core interoperability testing as well as research that involves being able to modify the 3GPP signaling interfaces.

The functional elements that would be implemented and our high level design blueprint is shown below;



IPG 5G WIRELESS RAN

Wireless Radio Access Network (RAN) – The RAN is the part of the wireless network that hosts the cell sites. RAN typically consists of cell site radios (eNodeB for 4G and gNodeB in the case of 5G), antennae, IP transport to the cell site and power. The RAN will be made up of the following elements,

4G Sub 6 Gigahertz cell sites (LTE based) – The radios will be installed at the RELLIS campus, Disaster City and within our deployable platform (trailer). The 4G radios will consist of Nokia ASIA and ABIA modules installed in an AirScale System Module or equivalent platform. Alongside the production eNodeBs. The platform will host National Instruments software defined radios (SDR) running Open eNodeB code. The sub six gigahertz 4G radios will primarily operate on the EBS spectrum (2.5 Ghz Band 41) and CBRS spectrum (3.5 Ghz Band 48).

We also intend to add Ericsson 4G small cells in an effort to maintain a multi-vendor environment. These will be used for interoperability testing and in building coverage. There are currently eNodeBs from Airspan, General Dynamics and Parallel Wireless in the lab.

In addition to the commercial nodes above we will have at least 4 eNodeBs that are developed on top of software defined radios allowing us to support research that modifies the protocol stack.

5G Sub 6 Gigahertz cell sites (LTE based) – The radios will be installed at the RELLIS campus, Disaster City® and within our deployable platform (trailer). The 5G radios will consist of Nokia ASIK and ABIL modules installed in an AirScale System Module or equivalent platform. Alongside the production gNodeBs, the platform will host National Instruments' software defined radios (SDR) running Open gNodeB code. The sub six gigahertz 5G radios will primarily operate on the EBS spectrum (2.5 Ghz Band 41) and CBRS spectrum (3.5 Ghz Band 48).

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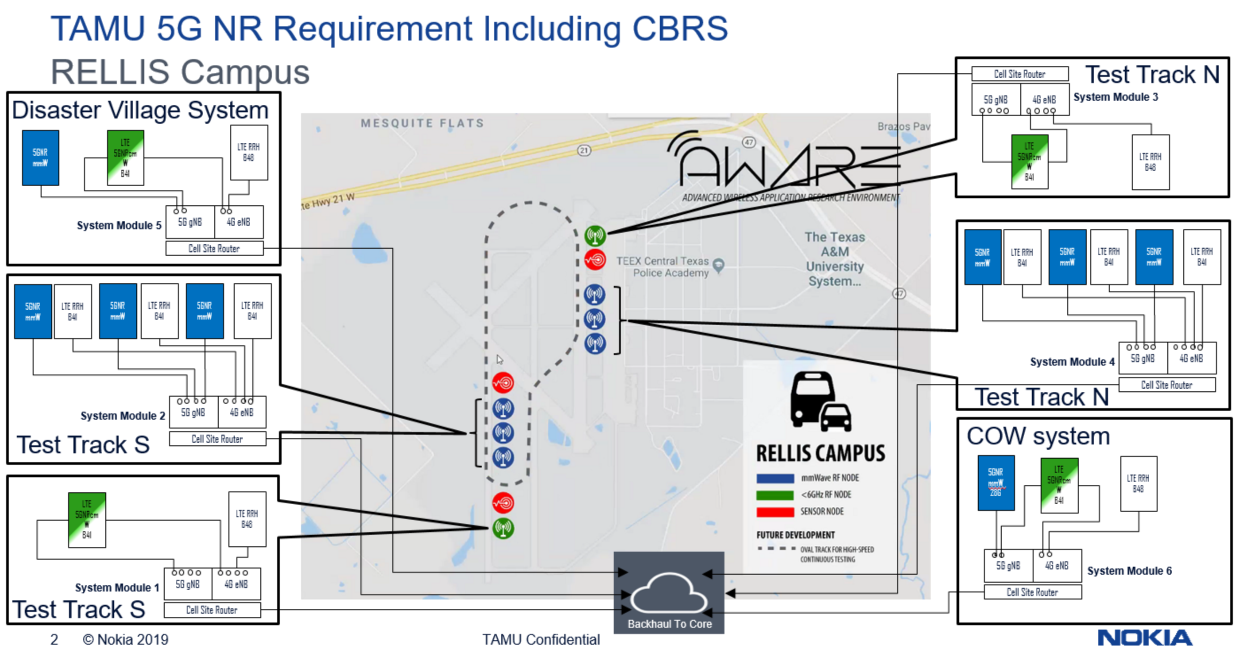
In addition to the commercial nodes above we will have at least 4 gNodeBs that are developed on top of software defined radios allowing us to support research that modifies the protocol stack.

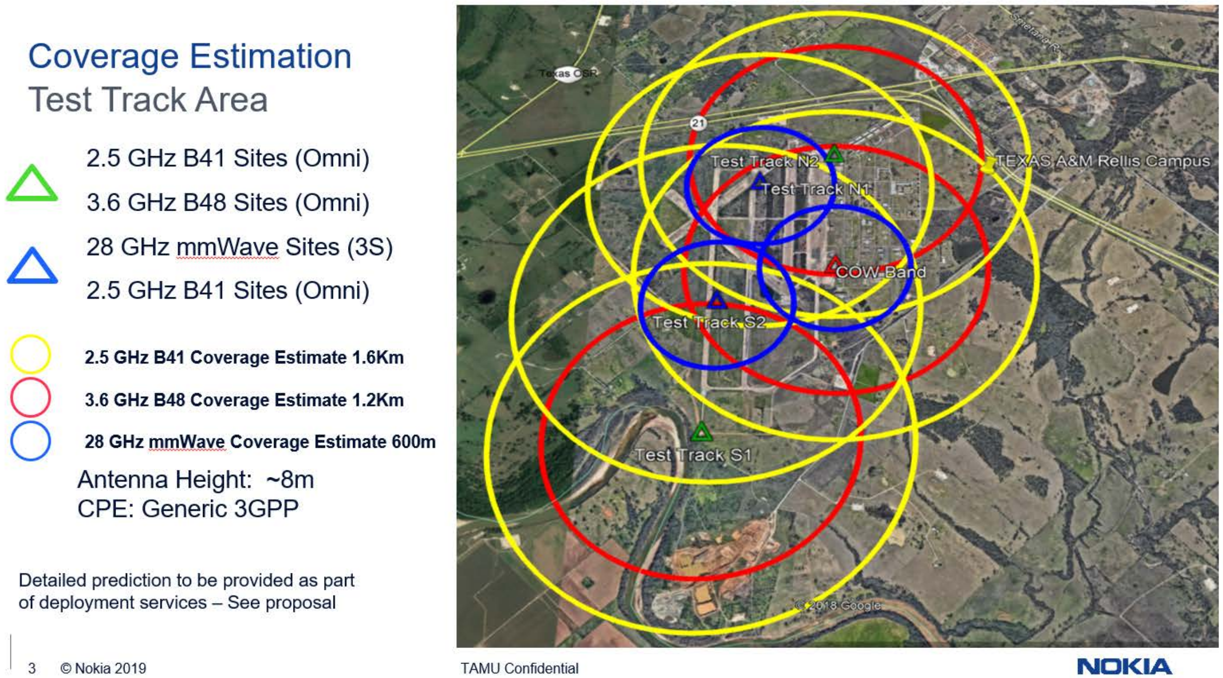
In building coverage testing would be provided with the installation of one of the RF chassis that supports both 4G and 5G RAN in building coverage. Installed in the MDF or lab of the buildings, we would use coaxial cable, splitters and remote antennae for the sub six gigahertz installations and fiber optic cable and rf reflectors for the mmWave frequencies.

5G Millimeter Wave cell sites – The 5G radios will be concentrated at the RELLIS campus and deployable node. The radios will be the Nokia ASIK and ABIL modules installed in the AirScale platform with 28 GHz RF modules which we will need to FCC license as an experimental network. The spacing on the millimeter wave nodes varies between 200m and 300m.

The network will also incorporated at least one up converter allowing the above 4G and 5G SDRs to be modified to support mmWave.



Cellular Coverage Expected



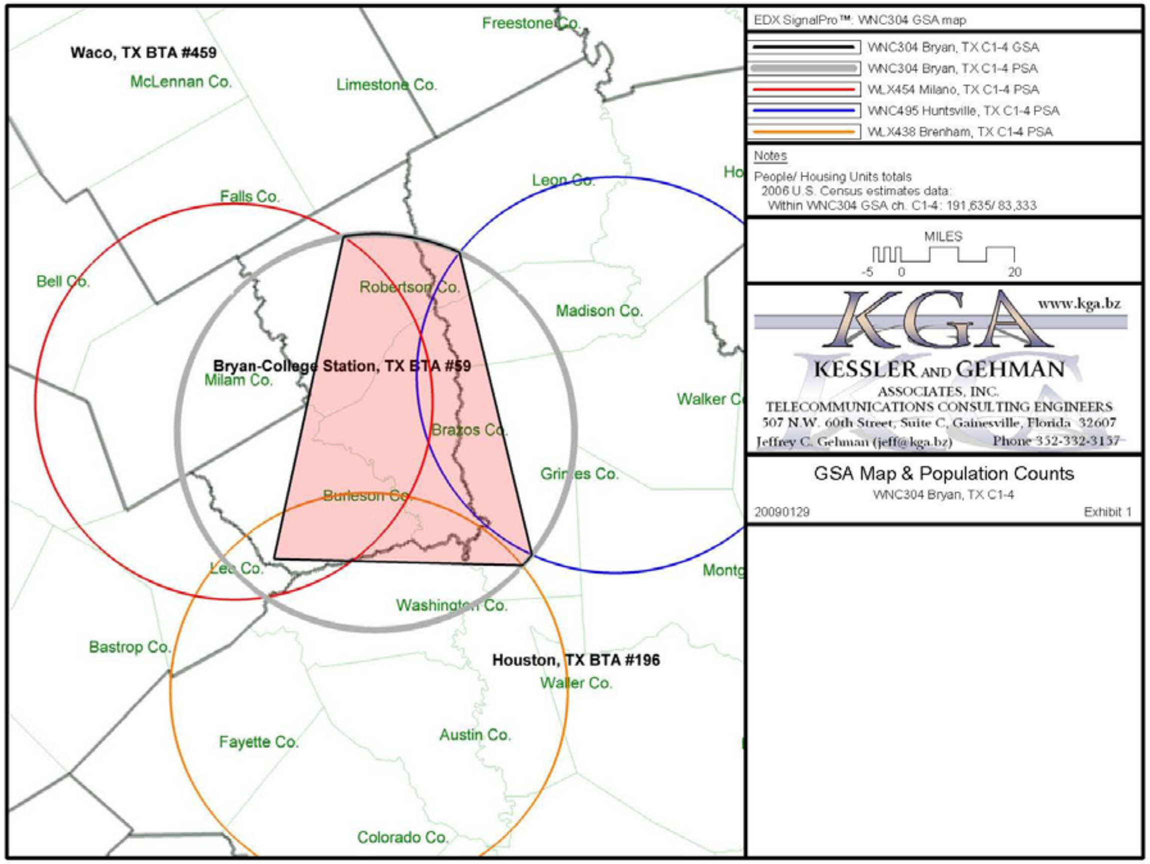
Spectrum to be used.

Frequencies to be used for IPG 5G WIRELESS platform.

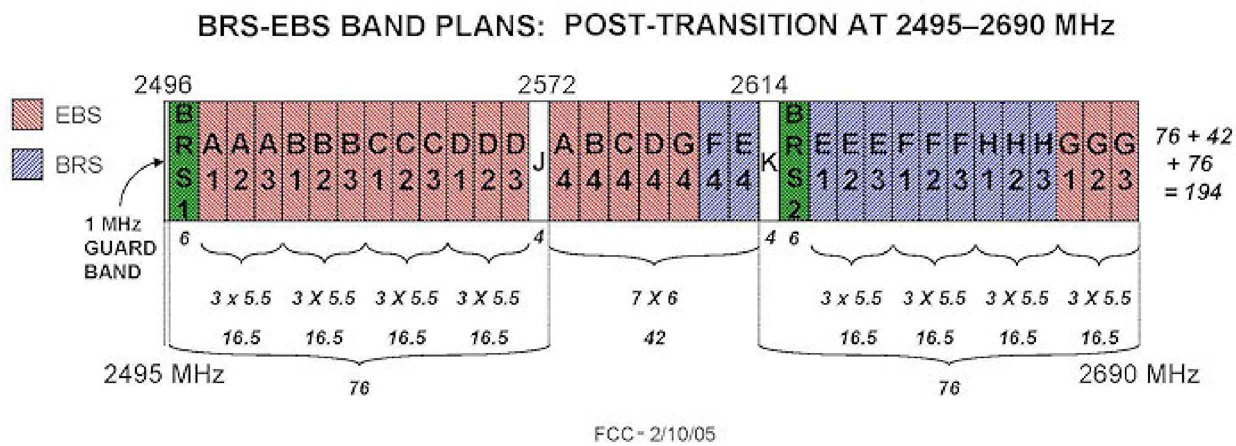
There are two types of frequencies that we are planning to use for the 4G/5G testbed. They are Educational Broadband Spectrum (EBS) in the 2.5 GHz frequency range and Citizens Broadband Radio Spectrum (CBRS) in the 3.5 GHz frequency range.

EBS Spectrum –

TAMU already has an FCC license for channels C1 thru C4 that is not in use today. The call sign for these channels is WNC304.   Bryan ISD, College Station ISD and Blinn College also have licenses for A1 thru A4, B1 thru B4 and D1 thru D4 which are also not in use today.



The colored in area above shows the areas where we are currently allowed to set transmitters. Note: This covers all of Brazos County. In addition we have requested FCC research licenses (referred to as an STA) for channels E1 thru E4, F1 thru F4, G1 thru G4 and H1 thru H4. Each of these channels is about 5 MHz. The following chart shows channel layout.



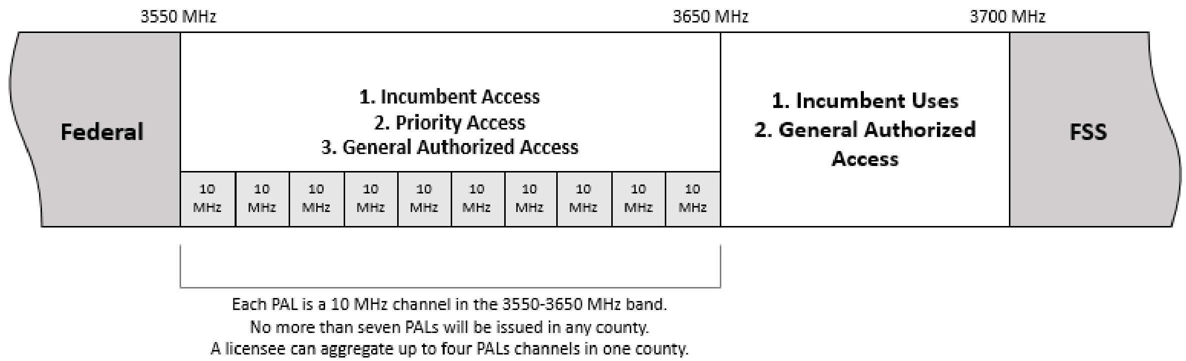
CBRS Spectrum

In June of 2019 the FCC opened up the CBRS spectrum to the public. This spectrum consists of approximately 150 MHz in the 3.5 GigaHertz band. These frequencies are designed to be shared in a method managed by a server referred to as the Spectrum Access Server (SAS). The SAS is queried at least once a day to get a spectrum allocation. At this time it appears that that will be 5 SAS vendors with Google, Federated Wireless and CommScope already being approved.

There are three levels of access for CBRS use;

1. Incumbent users including the U.S. Navy for ship mounted radar,
2. Around June of 2020 the FCC is going to hold an auction for up to 7 service providers,
3. General use.

We will determine if we should submit for one of the 7 licenses or we should use the no cost general use license. The TAMU ITEC is a CBRS Alliance member.



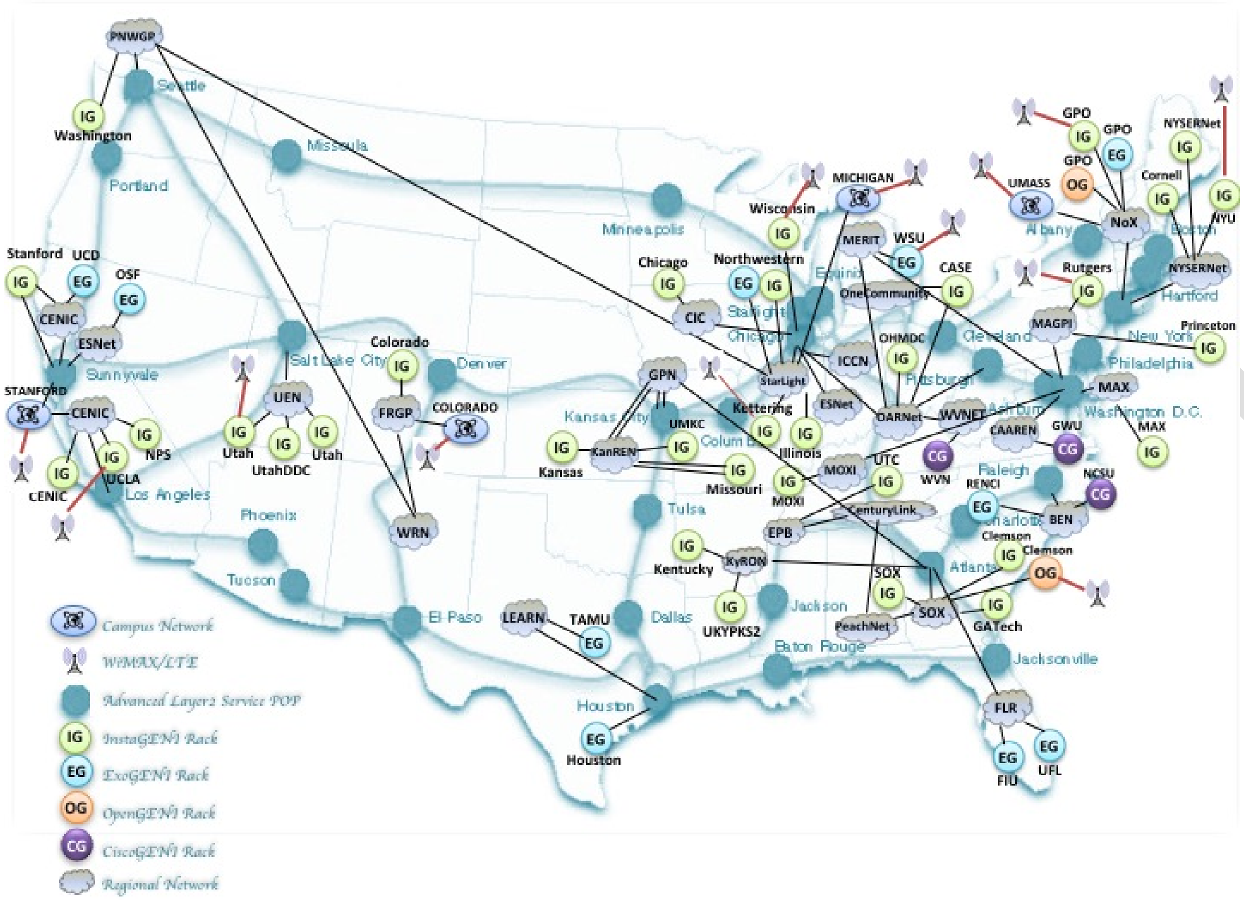
IPG 5G WIRELESS Enclosures. The 4G and 5G radios will be installed in environmentally controlled enclosures that are 4' wide, 4' deep and 5' high. These enclosures are designed to have enough additional space to allow us to add radios, edge cloud servers, monitoring systems or sensors in the future. Each cabinet has 24 single mode fibers and an access switch that is connected with a 10 gigabit per second link. Each cabinet also has a 35 amp 220 volt power panel. To support the antennae we are having 6" aluminum 20 foot masts manufactured that have flexible portals to allow for a diverse set of antennae configurations.

Deployable Platform – Augmenting the fixed units is a deployable node that is built on a Fast Runner trailer platform. This unit is a mobile version of IPG 5G WIRELESS enclosure with 4G and 5G cell nodes, an SDN router and edge cloud servers. The platform can either be attached to a fiber optic connection or it can connect through its own KA Satellite link. The Fast Runner can either connect to shore power or can run on its own generator.

IPG 5G WIRELESS Software Defined Network (SDN)

An important subsystem of the IPG 5G WIRELESS platform is the SDN. This network is used to provide interconnection between the RAN and the Core as well as RAN to RAN. 3GPP had defined the SDN as the transport layer to support the network slicing that is thought to be key to the success of 5G. SDN supports the stringent latency requirements of the 5G network and allow the distributed architecture that is made possible through core and RAN virtualization.

The IPG 5G WIRELESS platform will run over an OpenFlow architecture to be consistent with global research efforts. In the past the National Science Foundation or NSF supported a research and education SDN initiative through the GENI network. GENI was an OpenFlow network connecting 70 U.S. universities across the Internet2 network and several others internationally through global Internet2 partners. Texas A&M University has an ExoGENI node in the Wehner Building connecting several researchers to off campus sites.



In September of 2019 the NSF awarded $13 Million to the University of North Carolina to establish the next generation GENI network. This award titled **FABRIC: Adaptive Programmable Research Infrastructure for Computer Science and Science Applications** is intended to establish a Terabit per Second national backbone based upon a P4 enabled Openflow architecture. The Terabit Super-Core is intended to have a node in Houston (or Dallas) where the IPG 5G

WIRELESS platform would connect. We are currently in discussion with the University of North Carolina to begin planning for the FABRIC connection.

In addition to the FABRIC network another international networking initiative is beginning in the form of the **Wide area Infrastructure for TeCHnology Qualification, Readiness Assessment, and Full scale Transition** or WITCHQRAFT network. This is a global network virtualization effort built upon 4 years of software development (+200K lines of code) with a focus on 4G/5G wireless infrastructure. The WITCHQRAFT leadership has asked that IPG 5G WIRELESS become a demonstration site for the upcoming NSF proposal. TAMU would connect to the WITCHCRAFT fabric through the Intenet2 network.

The following diagram depicts the TAMU SDN architecture. This platform is built upon Openflow architecture delivered over Juniper routers. Juniper was selected for their open architecture and a promise to deliver P4 support in early 2020. These are both critical requirements if we are to connect to the global research community.

IPG 5G WIRELESS Cloud Platform

Another crucial subsystem of the 5G architecture is the Cloud. According to Wikipedia the Cloud is defined as "**Cloud** Computing is Internet-based computing, whereby shared resources, software, and information are provided to computers and other devices on demand, like the electricity grid".

The IPG 5G WIRELESS cloud platform is built upon a 4-tier structure. These four tiers are tightly coupled allowing the application to select the network resources, processing power, memory and storage that is most appropriate for the current needs. The four tiers include:

1. Edge Cloud - This is made up of nodes that are located at the cellular network sites. This is the processing with near zero latency network requirements. Applications could include vehicle to infrastructure (V2I) information for autonomous vehicles, analytics for localized video and IoT, and network element virtualization to support network outages. These servers will consist of a combination of Dell R640 servers and Dell R440 Servers. R640 servers were added due to their support for GPU and FPGA add on modules.

    Specification for the R640: Cloud Edge
    CPU: Dual Intel Xeon Gold 4208 2.1G 8C or better
    Memory: 192GB (12x16GB DIMMS) Expandable up to 768GB
    Network 1: Intel V710 Quad 10GbE Base-T
    Network 2: XXV710 Dual port 10/25GbE SFP28 or SFP+
    Boot: Boss Controller RAID 1, 480GB M.2
    Storage: 3 x 1.6GB Mixed use with PERC RAID 740P Controller
    Support: 5 year, Next Business Day HW with 7x24 technical support
    Software: VMWare vSphere 5 years.
    Optional GPU/FPGA: Up to 3 single-width GPU (NVIDIA T4) or up to 1 FPGA

2. Middle Cloud - This layer has also been referred to as the Central Office Re-architected Cloud or CORD. It would augment the edge cloud with latency of up to about 5 milliseconds of latency. The major service providers all have hardened facilities that were originally designed to support large telephone switches which have since been replaced by soft switches. These servers would be the Dell 640 model servers.

    Specification for the R640: CORD servers
    CPU: Dual Intel Xeon Gold 4208 2.1G 8C or better

Memory: 192GB (12x16GB DIMMS) Expandable up to 768GB
Network 1: Intel V710 Quad 10GbE Base-T
Network 2: XXV710 Dual port 10/25GbE SFP28 or SFP+
Boot: Boss Controller RAID 1, 480GB M.2
Storage: 3 x 1.6GB Mixed use with PERC RAID 740P Controller
Support: 5 year, Next Business Day HW with 7x24 technical support
Software: VMWare vSphere 5 years.

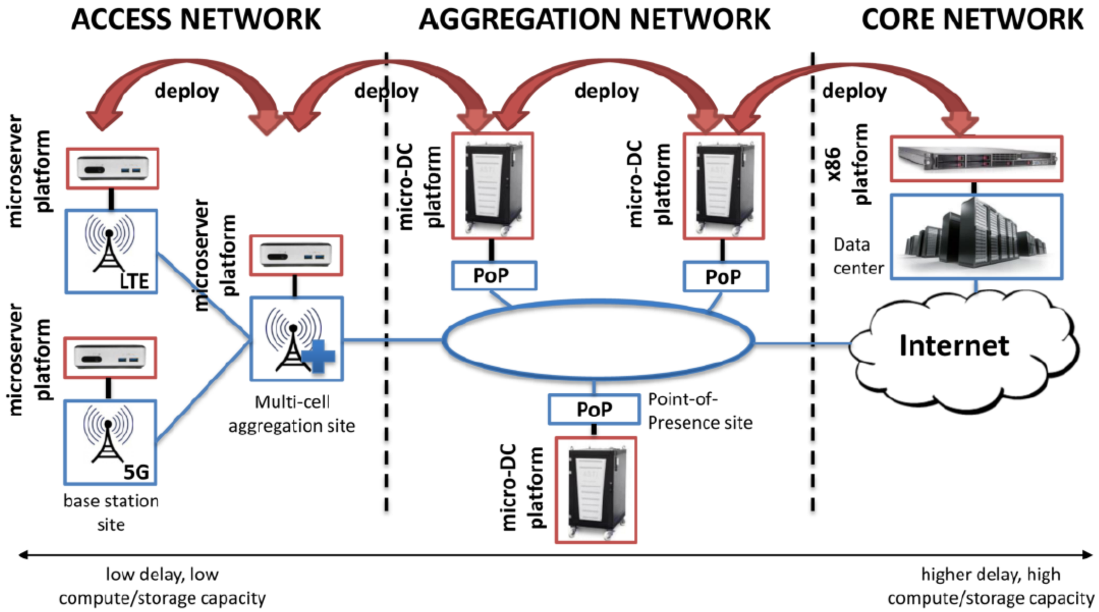
3. Private Cloud – This series of servers would initially be installed at the TAMU ITEC lab but would likely be moved the RELLIS data center once built. Private Cloud is required for specific latency sensitive applications since there is no way to assure packet loss and latency over the Internet. This would be a series of R740 servers two of which would be installed in year one and two in year two.

Specification for the R740: Private Cloud
CPU: Dual Intel Xeon Gold 6244 3.6G 8C or better
Memory: 192GB (12x16GB DIMMS) Expandable up to 768GB
Network: Broadcom 57414 Dual Port 10/25 GbE SFP28 or SFP+
Boot: Boss Controller RAID 1, 480GB M.2
Storage: 6 x 3.84GB Mixed use with PERC RAID 740P Controller
Support: 5 year, Next Business Day HW with 7x24 technical support
Software: VMWare vSphere 5 years.

4. Public and Secure Cloud – Many of the applications will be run in the Amazon, Google and other cloud facilities. These facilities would be connected through the FABRIC SDN network allowing us to minimize network impact.

A depiction of this architecture is shown below

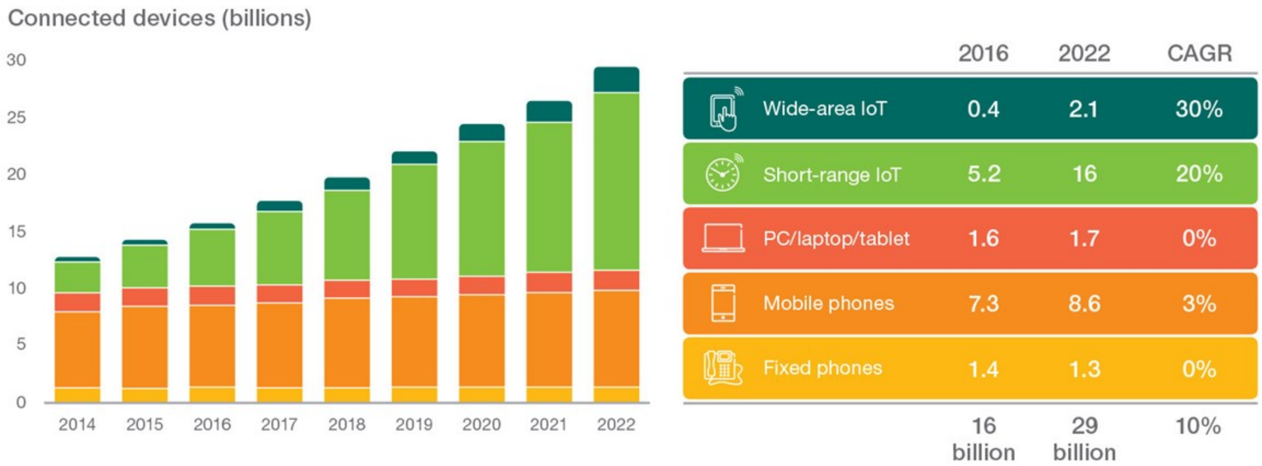
Figure 9: A Preliminary Converged Cloud-Based 5G Architecture



Source: SuperFluidity

IPG 5G WIRELESS IoT Platform

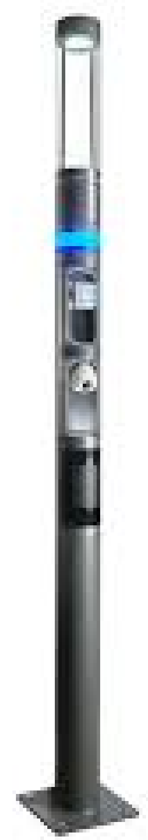
IoT is considered to be a large part of the 5G ecosystem yet there is little understanding today how we are to identify it, classify it, secure it, store it or share it. An Ericsson study estimates that there will be 29 billion IoT devices by the year 2022.



In order to support IoT the IPG 5G WIRELESS testbed will contain IoT aggregation platforms. These platforms are anticipated to come in two form factors, one being a ground mount device and one being a street light mounted device. TAMU already has a contractual relationship with the manufacturers of these two devices. The ground mount unit is the Shreader Shuffle and the light pole mounted unit Wi-Fiber. Both units would be installed with 4G user elements in year one and converted to 5G user elements in year 3.

Initially certain IoT devices will be installed in these units but the system is designed with the flexibility to allow us to add new devices as they become available. Early IoT sensors will include surveillance cameras, shot spotters, and environmental sensors. Supporting a DHS grant, we will add Weapons of Mass Destruction (WMD) sensors in year 2.

The IPG 5G WIRELESS IoT aggregation support systems are shown below.



Above is the Schreder Shuffle. It is a twelve foot tall eight inch cylinder that is highly modular to be able to support IoT devices. It would contain two 20 amp 120 VAC outlets to support IoT systems. The communications interface would be a 4G/5G user element (UE) device, much like the 5G devices designed to support home communications. This would be the IoT hub. There would also be a small form factor edge server supporting localized analytics and short term storage.

Above is the WiFiber street light head. It is a self contained street light replacement head that contains two remore controllable LED street light bulbs. It would contain two 20 amp 120 VAC outlets to support IoT systems. The communications interface would be a 4G/5G user element (UE) device, much like the 5G devices designed to support home communications. This would be the IoT hub. There would also be a small form factor edge server supporting localized analytics and short term storage. The unit contains a build in HD camera but has the ability to support additional cameras.

IPG 5G WIRELESS Cybersecurity Platform.

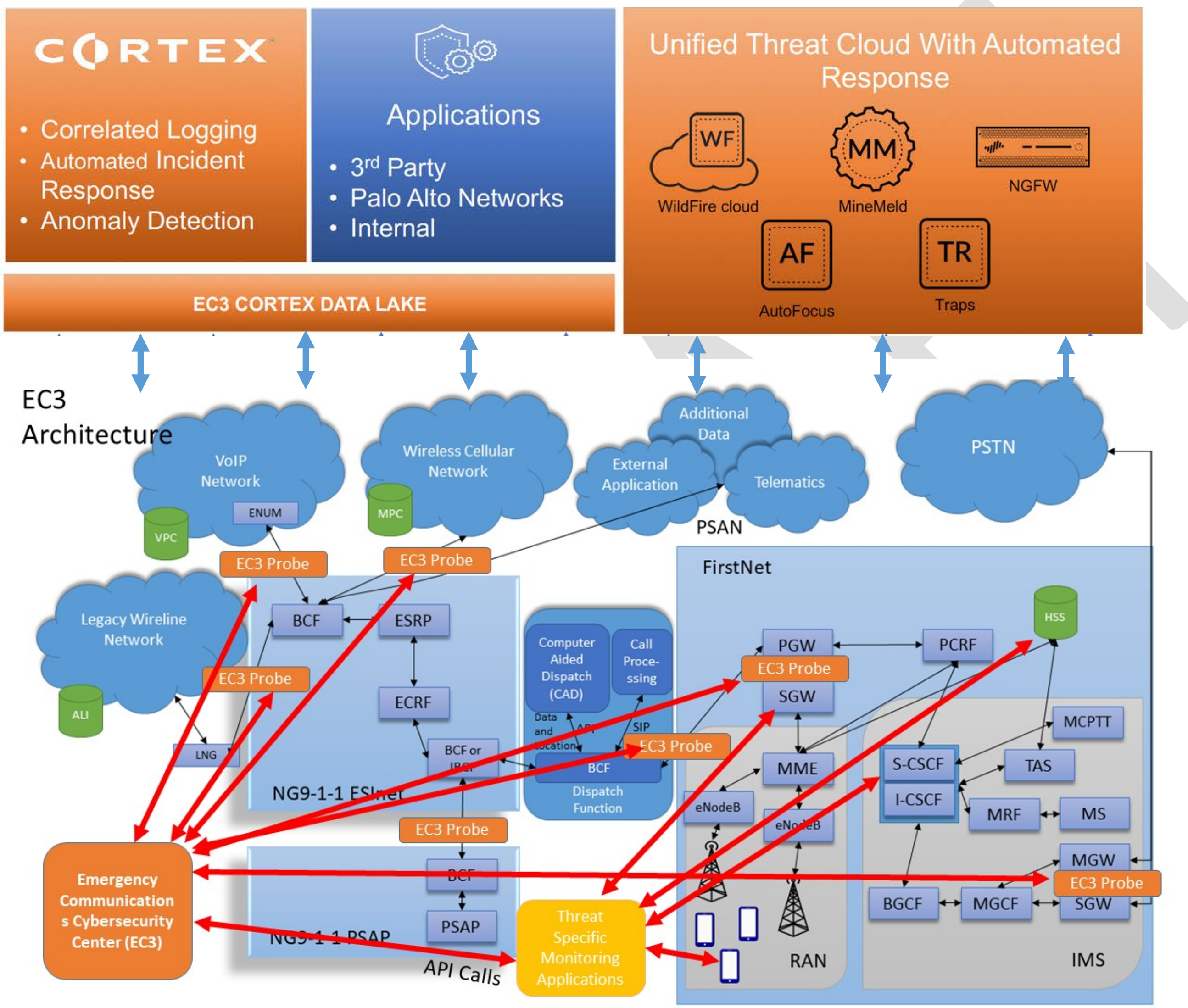
The cybersecurity platform needs to perform two functions: (1) secure the IPG 5G WIRELESS platform so that outside world cannot disrupt operations of the testbed, and (2) host security appliances that could be used in developing, testing and training 5G cybersecurity systems.

Initially the testbed will consist of:

- Juniper SRX 4600 Firewall with 100 and 40 gigabit per second interfaces. This will be the boundary firewall;
- Oracle (Acme Packet) 3820 Session Border Controller - This will manage all real-time audio and video (SIP and other protocols); and
- Palo Alto Cortex platform that supports deep packet inspection, logging analytics and other functions.

The project would fund both Juniper and Palo Alto support during the first two years as we build our cybersecurity team.

Below is the proposed CyberSecurity Architecture



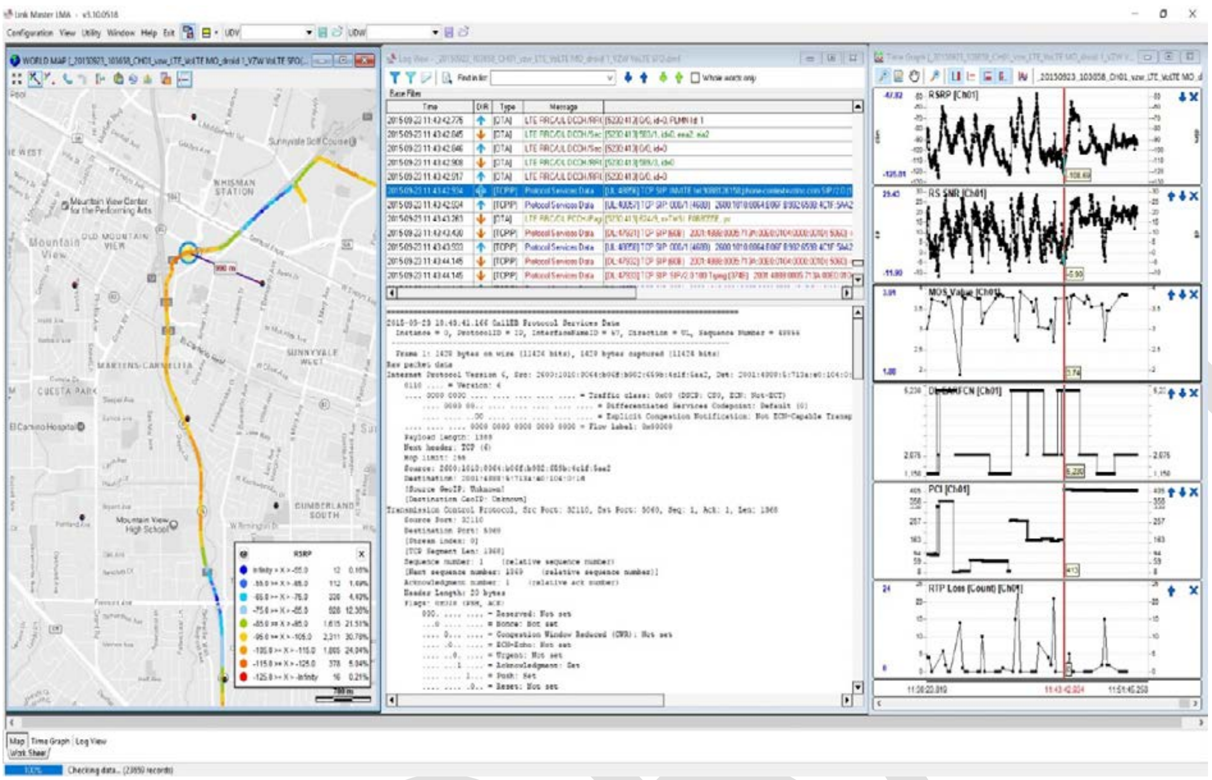
IPG 5G WIRELESS Data Collection (Test Systems) Platform

The IPG 5G WIRELESS testbed would be equipped with RF and Data collection systems that would allow a researcher to collect and analyze raw data in the conduction of research. The equipment is broken down into the following subsystems:

- **Umetrix User Experience test solution.** These portable field test tools serve multiple purposes for users of the IPG 5G WIRELESS test platform.
    1. Objectively measure and analyze the user experience (human and machine) of voice, video, data applications and services rendered on mobile platforms and the performance of mobile devices. The solution captures time synchronized data including user experience (MOS, bandwidth, latency), RF signal and bearer data, protocol messages, IP impairments (packet loss)), location/drive route. This multi-dimensional view will enable researchers to easily evaluate performance and narrow down cause of performance issues.

    2. Network loading with real devices and applications. The Umetrix test solution enables concurrent testing, where multiple mobile devices can be instrumented in an automated fashion to concurrently perform actions and run applications on the IPG 5G Wireless test bed network – voice calls, video streaming, file UL/DL, multiservice functions, etc. The scenario can include a combination of device types and access technologies (4G/5G). This capability will enable researchers to create congested network scenarios while testing and evaluating the performance of an application, service, device, or platform under test. This solution is intended for loading small scale networks (tens to hundreds of users) with real devices and traffic.

    3. Visual presentation of results/analysis. The results are presented in the graphical and tabular forms using the post processing tools and comparison reports for meaningful analysis of the collected data. Below is an example.



- **Spirent GSS6450.** This small portable device can be placed in any vehicle. The device can simultaneously record and captures multiple technologies including GPS/GNSS, Wi-Fi, LTE, canBUS, video and audio. This drive test data is stored on an embedded storage device and played back at a later time to recreate or analyze events. The 6450 record/playback device also includes an on-board spectrum analyzer that shows a visual representation of the RF environment at any given time during the test. All files that have been captured on this device can also be saved as files on a network drive and retrieved at any time for further analysis or playback.

- **SimSafe GNSS7725 and GSS7000 system.** This solution allows vulnerability and interference testing for Positioning, Navigation and Timing (PNT). The system can be used to transmit a live GNSS signal as well as interference, jamming and spoofing capabilities. They are used under controlled testing environments since they create a realistic signal. The system does have the ability to span across multiple frequencies (L1, L2, L5), as well as, support all major constellations (GPS, Glonass, Galileo, Beidou) The system is controlled through Spirent Software, but can easily be automated or integrated with other systems since control is also possible through open source commands.